STREAM HABITAT RESTORATION GUIDELINES

NOTE TO THE READER: THE FOLLOWING DRAFT IS INCOMPLETE. TEXT THAT IS HIGHLIGHTED IN PURPLE INDICATES TOPICS YET TO BE COVERED.

1 INTRODUCTION

2 CHANNEL PROCESSES AND RESPONSE TO STREAM AND WATERSHED DISTURBANCES

2.1 *Fluvial Processes that Determine Channel Morphology and Stream Habitat Diversity*

Aquatic habitat is a product of the fluvial processes that operate at a watershed scale (Hill et al. 1991, Gore 1985, Poff et al. 1997, Spence et al. 1995). According to the dictionary, process is defined as “a series of actions, changes, or functions that bring about an end or result”. The principal processes that create and maintain stream channel conditions include those that influence the supply, storage, and transport of water, sediment, energy (light and heat), nutrients, solutes, and organic matter including woody material and leaf litter (Spence et al 1995, Roni et al 2002, Joint Natural Resources Cabinet 2001, Miller 2001, Benda et al. 1998). These processes vary in time and space and are controlled by the interaction of climatic and physical conditions (e.g., geology, topography, channel network, and basin history) within a watershed (Ontario Ministry of Natural Resources 1994, Benda et al. 1998). Basin history includes the temporal sequence of past climatic and erosive events as well as human modification of the landscape.

Other factors that govern the form of a stream channel include the extent and type of the riparian vegetation, the nature of the materials through which the stream flows (e.g., boundary materials), and direct human modification of the channel (Church 1992). Riparian vegetation has direct and indirect effects on channel form. Its indirect effect lies in that it serves to buffer the stream from disturbance within the watershed, thereby controlling the amount of water, sediment, and other material entering the stream channel. Riparian vegetation directly affects channel form by contributing to streambank stability and the hydraulic roughness of the channel, and by providing a source of large woody material to the stream. Large woody material influences the formation and quality of pools, bars, and steps, contributes to the hydraulic roughness of the channel, and causes armoring or erosion of streambanks (Montgomery and Buffington 1998).

The boundary materials of a stream determine the constraints imposed to channel movement and adjustment. Boundary materials may be classified as colluvial, bedrock, or alluvial.

> *Colluvial* reaches are those in which the boundary materials are dominantly deposited by the surrounding hillslopes through mass wasting events such as landslides. Their form may be extremely variable as it is controlled by discrete events. Colluvial reaches typically occupy headwater portions of a channel

network and occur where steep slopes are present and geologic degradation is ongoing. Their shallow, sometimes ephemeral flow is incapable of transporting the coarser fractions of their sediment supply. As such, their channel beds typically consist of boulders, cobbles, and gravels. Colluvial reaches have limited ability to adjust their form due to local controls by erosion resistant materials. Colluvial reaches are "source" reaches. That is, their sediment supply typically exceeds their sediment transport capacity. (Montgomery and Buffington 1998, Miller 2001)

Bedrock reaches are typically confined by rock valley walls and lack floodplains. They tend to be relatively straight and do not change position in time unless relatively weak zones in the bedrock allow the channel to shift laterally or vertically. Channel floors typically consist of either exposed rock or thin patches of alluvium. In general, bedrock reaches in low-gradient portions of a watershed reflect a high transport capacity relative to sediment supply, whereas those in steep debris-flow-prone channels may also reflect recent debris flow scour. (Montgomery and Buffington 1998, Miller 2001)

Alluvial reaches are "self-formed" channels, bounded by bed and bank materials that were transported and deposited by the stream itself. As such, they are free to adjust their form through erosion and deposition. Alluvial reaches transport and sort sediment loads transported from upslope, but lack the transport capacity to routinely scour the valley to bedrock. Alluvial reaches may have narrow or wide floodplains and may exhibit a wide variety of bed morphologies, depending upon the relationship between the channel's transport capacity and sediment supply. (Montgomery and Buffington 1998, Miller 2001)

All river channels are dynamic by nature, continually adjusting to their supply of sediment and water (Miller 2001). Changes in supply may be gradual or abrupt. An abrupt change may result from floods, windstorms, fires, landslides, debris flows, and volcanic eruptions that cause a significant disturbance in the watershed and lead to a biological response (Pickett and White 1985). Disturbances may vary in their extent (e.g., they may be site-based or watershed wide), location, magnitude, and frequency. Collectively, these characteristics make up the disturbance regime of a watershed.

Streams and floodplains have historically been subject to periodic catastrophic disturbances. Disturbance in the stream or watershed can pose an environmental risk, but it also serves as a mechanism for creating and maintaining aquatic and floodplain/riparian habitat (Benda et al. 1998). The diversity of riparian vegetation and floodplain water bodies (e.g., periodically isolated side channels, ponds, and wetlands) is directly related to the frequency and magnitude of disturbance events that reset these communities to earlier successional stages (Ward et al. 2001, Cowx and Welcomme 1998, Vannote et al. 1980). These plant communities and waterbodies would otherwise continue on a trajectory towards terrestrialization; abandoned meander bends eventually becoming merely a wet depression on the floodplain. Disturbance can cause abrupt changes in habitat conditions, altering hydrologic and nutrient cycling processes; reconfiguring the stream channel; creating and filling pools, oxbows, side channels, and off-channel ponds; and redistributing sediment and organic matter so as to create and erode islands, bars, streambanks, and floodplains. The temporal and spatial variability of disturbance creates a mosaic of habitats representing various serial stages of succession and recovery across a watershed in any given year (Ward et al. 2001, Benda et al. 1998, Reeves et al. 1995).

2.2 Physical Characteristics of Streams – Not Available at this Time

Define, characterize, and explain importance of each parameter.
This section will summarize and refer to the Geomorphology Appendix and the Channel Design White Paper where appropriate.

- Channel pattern
- Channel morphology (cascade, step pool, pool riffle, dune ripple, plane bed)
- Channel bedforms--
    - pools
    - bars
    - riffles/shallows
- Substrate
- Small and large woody material
- Floodplain/Confinement
- Riparian Vegetation
- Stream Classification Systems

2.3 Stream Habitat

The diversity, abundance, and species of aquatic organisms present in a stream depend on the pool of species available for colonization and on local environmental conditions (Allan 1995). The preferred physical, chemical, and biological environment of fish, reptiles, amphibians, macroinvertebrates, mammals, and other aquatic life varies between seasons, species, and stages within the life cycle of any one species. Therefore, diverse habitats have a higher potential to support a productive and diverse biotic community than simple habitats (Hill et al. 1991, Gore 1985, Poff et al. 1997, Pollock 1998). Survival of a species depends on the existence of, and access to, its reproductive, feeding, and refuge habitats. Characteristics that define the preferred habitat of an aquatic organism include abiotic variables such as the structural complexity of the stream, light intensity, water depth and velocity, stream substrate, temperature, and water quality, and biotic variables such as exposure to predation and competition (Cowx and Welcomme 1998). These habitat characteristics influence the quality and amount of food (energy) available, the amount of energy expended for metabolic processes, and hence the amount available for growth and reproduction (Spence et al. 1995).

The ecology of a stream expands beyond the channel itself, encompassing the entire stream corridor. A stream corridor is comprised of the stream channel, its shoreline, the hyporheic zone, and the surrounding floodplain and riparian zone. The corridor encompasses aquatic and terrestrial habitats and provides a connection between them. The structure of habitat within the stream corridor has three physical dimensions: longitudinal, lateral, and vertical (Cowx and Welcomme 1998, National Research Council 1992, Naiman et al. 1992, 1995). The structure of habitat also varies along a forth dimension, and that is time. Note that, because ecosystems are dynamic in space and time, suitable habitat may not be available to all species in all streams at all times (Reeves et al. 1995).

2.3.1 Longitudinal Habitat Connectivity

The longitudinal dimension of the stream corridor describes the upstream/downstream component. Streams are characterized by a one-way flow of water that conveys energy, nutrients, sediment, organic material, and pollutants from the headwaters, floodplains, and shoreline to the mouth. The physical conditions within the channel (width, depth, velocity, temperature) vary in response to water, sediment, and organic inputs from the watershed and so create a mosaic of habitat along the length of the stream. Biotic communities that form within a stream vary and are dependent upon their physical, chemical, and biological environment.

Discuss typical changes in habitat as one moves from a stream's headwaters to its mouth.

One way of conceptualizing variation in the structure of biological communities in a stream as one moves from source to mouth is offered by the river continuum concept developed by Vannote et al. (1980). According to the river continuum concept, changing physical conditions, including organic matter loading, transport, and storage along the length of a stream create a continuous gradient in stream habitat conditions as one moves from the headwaters to the mouth. This prompts a corresponding gradient in the biotic community, resulting in "consistent patterns of community structure and function". Organic matter provides a source of energy to the biotic community of a stream.

To illustrate the River Continuum Concept the authors of the concept subdivide streams into three sizes.

1. Headwater streams (1^{st} to 3^{rd} order streams) are influenced strongly by riparian vegetation. They are predominantly accumulators, processors, and transporters of materials from the terrestrial system. Their primary source of organic input comes from the terrestrial zone through leaf fall and woody debris.
2. Medium-sized streams (4^{th} to 6^{th} order) have a reduced reliance on the terrestrial zone and a corresponding increased reliance on primary production (e.g., algae and aquatic plants) within the stream as a source of locally-derived organic material. It also receives organic transport from upstream. This point at which the shift occurs in the relative importance of organic material supply is primarily dependent upon the degree of shading.
3. In large rivers (($>6^{th}$ order), the effect of riparian vegetation is insignificant to the stream's supply of organic material.

As a result of physical and biological processes, the particle size of organic material being transported by the stream become progressively smaller as the stream size increases. There is a corresponding shift in the biotic community to one that is more efficient at processing smaller particles.

The river continuum concept has two basic limitations (Junk et al. 1989, Sedell et al. 1989). These include that 1) it was developed on small temperate streams that originate in mountainous, forested watersheds, and 2) It only considered permanently flooded habitats and did not take into account the effects of periodically inundated floodplains on the stream. As such, while it provides useful predictions of longitudinal ecosystem characteristics for streams with limited floodplain interaction, most large floodplain-river systems cannot be adequately addressed using the river continuum concept (Sedell et al. 1989). Sedell et al. (1989) and Junk et al. (1989) suggest that the habitat of systems with floodplains is more accurately described as a sequence of patches of varying lengths and widths, and not a simple continuum, especially for systems characterized by regular floods of long duration.

2.3.2 Lateral Habitat Connectivity

The lateral dimension of the stream corridor runs perpendicular to flow. Streams have a lateral structure that begins at the main channel and progresses through the channel margin and floodplain/riparian habitats to the adjacent terrestrial environment. Riparian/ floodplain habitats may consist of side channels, off-channel ponds and wetlands, perennial or intermittent streams and springs, and periodically-flooded grasslands and forests (Cowx and Welcomme 1998). These riparian/floodplain habitats offer feeding, reproduction, and refuge habitat for invertebrates, fish, waterfowl, amphibians, birds, and mammals.

Floodplains and riparian zones overlap in their extent; riparian zones include both the active floodplain and the adjacent plant communities that directly influence the stream system (Knutson and Naef 1997). By definition, floodplains are "areas that are periodically inundated by the lateral overflow of rivers or lakes, and/or by direct precipitation or groundwater" (Junk et al 1989). Riparian zones are defined as the land adjacent to streams, rivers, ponds, lakes, and some wetlands, whose soils and vegetation are influenced by the presence of the ponded or channelized water (Slaney and Zoldokas 1997).

The relative importance of floodplains to stream ecology increases with the regularity, duration, and extent of inundation. These in turn vary with the hydrology of the stream and the entrenchment of channel (related to the degree to which the valley is constrained and/or the stream is incised). Relatively small drainage areas and steep hillsides limit the duration and extent of flooding in low-order headwater streams (Sedell et al.1989). In contrast, large streams flowing across unconfined valley floors generally have extensive complex floodplains that remain flooded for long durations.

Flooding is an essential ecological interaction between the river channel and its associated floodplain (Junk et al. 1989, Benke et al., Tockner et al.). Flooding creates, maintains, modifies and destroys physical floodplain features such as bars, levees, swales, oxbows, backwaters, and side channels. Flowing water sorts sediments creating floodplain soils that are stratified both vertically and horizontally. And floodwaters carry sediment, organic material, nutrients, and biota to and from the floodplain. The varied floodplain topography creates a gradient of depth and duration of flooding. Every plant has an optimal position along this hydraulic gradient. The hydraulic gradient, coupled with variations in soil structure, vegetation, and topography create a complex and dynamic network of habitats throughout the floodplain. (Junk et al. 1989)

Floodplains alternate between aquatic and terrestrial environments and the change can be stressful, or even detrimental, to the affected biota. The biological response of biota to the dynamic floodplain environment varies with the regularity, frequency, and duration of inundation as well as the rate of change. Headwater streams are characterized by rapid, unpredictable changes in flow as their hydrology is strongly influenced by precipitation events. In contrast, large streams and rivers with access to extensive floodplains typically have a more predictable flooding regime.

> *"Unpredictable flood pulses generally impede the adaptation of organisms and are counter productive for many of them. Conversely, a regular pulse allows organisms to develop adaptations and strategies for efficient utilization of habitats and resources within the aquatic-terrestrial transition zone, rather than depend solely on permanent water bodies or permanent terrestrial habitats… Regular pulsing coupled with habitat diversity favors high diversity of aquatic and terrestrial plants and animals, despite considerable stress that results from the change between terrestrial and aquatic phases."* (Junk et al. 1989)

In addition to offering feeding, reproduction, and refuge habitat to aquatic and terrestrial species, floodplain/riparian zones also have a significant influence on in-stream habitat. Depending on the type, extent, and density of riparian vegetation, riparian areas may provide the following critical functions to streams, whether or not they ever come in contact with flood water:

- Provide shade which helps to moderate stream temperature, providing relatively cool water in summer and warm water in winter
- Improve water quality
- Retain water during storm events and release it slowly over time, providing longer-term base flow contributions
- Stabilize stream banks
- Provide a source of large and small woody material to the stream which can act as sediment storage areas and enhance pool depth and quality
- Provide cover
- Provide a source of roughness to the stream
- Provide a source of leafy debris that is an important food source for aquatic invertebrates

When riparian areas are accessible to flood water, they have the additional benefits of reducing the depth of in-stream flow during high-flow events, thereby lowering the sediment carrying capacity of the stream (and, in turn, bed and bank erosion) and the buoyancy of woody material. Floodplains may also provide a source or sink of nutrients, pollutants, and organic material to the stream.

Discuss importance of fringe habitat

2.3.3 Vertical Habitat Connectivity

The vertical dimension of in-stream habitat refers to the physical, chemical, and biological interaction between the water column and its underlying bed. Discuss specific importance of substrate to macroinvertebrates and fish (salmon, trout, grayling) and wildlife that lay eggs in the substrate.

The hyporheic zone is the "volume of saturated sediment beneath and beside streams and rivers where ground water and surface water mix" (Edwards 1998). Recognition of the hyporheic zone and its relevance to streams is a relatively recent occurrence and much about it is still poorly understood. According to a literature search by Edwards (1998), the importance of hyporheic zones to stream ecology lies in the following:

- They influence surface water quality (Bencala 1984);
- They influence the efficiency with which solutes are retained and processed in the stream (Balett et al. 1996);
- They contribute to the decomposition of organics in the stream (Pusch 1996);
- They provide habitat to diverse and abundant fauna (Smock et al. 1992);
- They may serve as refuge for steam biota, buffering them from disturbance in discharge and food supply (Valett et al. 1994); and
- They are one of the dominant links between the riparian zone and the stream channel.

The distribution and extent of hyporheic zones in the watershed depends upon the distribution, size, and texture of sediment. In most cases, the hyporheic zone is of limited extent, but in some settings, such as broad alluvial valleys comprised of permeable gravel, the hyporheic zone can be quite extensive (Cowx and Welcomme 1998).

Hyporheic flow can only occur in sediments with adequate hydraulic conductivity and where there is an adequate gradient in hydraulic head to overcome the resistance of the sediments to flow. The hydraulic conductivity of the hyporheic zone increases with sediment size and the degree of sorting that has occurred during and after sediment deposition. An abundance of fines can reduce the hydraulic conductivity of the sediment.

Hyporheic flow can operate at a reach, channel unit or roughness element scale. An example of reach scale hyporheic flow is what happens when a stream enters a wide alluvial valley before the surrounding hillsides confine the stream once again. In such an example, downwelling from the stream will occur at the upstream end of a valley and upwelling will occur at the downstream end as the valley walls becomes confined. Channel unit scale hyporheic flow occurs between a series of pools. Water downwells at the downstream end of the upper pool and upwells into the upstream end of the lower pool. Roughness element scale hyporheic flow may occur around a riffle constriction or other obstruction to flow. (Edwards 1998)

For a more thorough discussion of hyporheic flow, refer to Edwards (1998).

2.3.4 Effect of landscape disturbance on biological diversity

Disturbance strongly influences the structure and composition of biotic communities (Krebs 1994), having both direct and indirect effects. Direct effects include mortality that occurs during the disturbance event. For instance, a landslide into a stream channel may crush or bury organisms directly in its path. Indirect effects include those associated with the resulting change in habitat conditions immediately following the disturbance (discussed in Section 2.1) and during the system's recovery.

Native species evolved with the natural (historic) disturbance regime of their stream system and have developed a suite of adaptations for survival (Benda et al. 1998). Their response to disturbance depends on the duration, intensity, and frequency of the disturbance (Reeves et al 1998), the sensitivity of the channel (Hogan and Ward 1997), the abundance and distribution of new and undisturbed habitat, and the abundance, distribution, sensitivity and adaptive capability of the surviving populations.

Yount and Neimi (1990) describe two types of disturbance, "pulse" and "press". A pulse disturbance is one that allows an ecosystem to stay within its normal range of conditions and eventually recover to its pre-disturbance condition (e.g., floods). A press disturbance is one that forces an ecosystem into conditions outside its normal range (e.g., dams). Stream biota may not survive habitat alterations caused by press disturbances if the altered conditions lie outside their adaptive capabilities (Gurtz and Wallace 1984). Many anthropogenic activities in the stream and watershed cause a press disturbance (Yount and Neimi 1990).

The intermediate disturbance hypothesis (Connell 1978) suggests the role that disturbance plays in structuring biological communities. It was initially developed to explain the diversity of tropical rain forests and coral reefs, but has since been applied to a variety of other systems including natural and altered streams (Ward and Stanford 1983). The intermediate disturbance hypothesis predicts that biotic diversity will be greatest in systems that experience moderate levels of disturbance. Disturbances that are too frequent or too intense are thought to suppress biotic diversity by causing local extinction of certain species and/or dominance of colonizing species (Ward and Stanford 1983, Spence et al. 1995). In systems that experience infrequent disturbance, competitive interaction of species becomes the dominant force that determines the structure of biological communities; superior competitors tend to dominate (Ward and Stanford 1983). Some moderate level of disturbance allows colonizing species to coexist with superior competitors as neither species and favored.

2.4 Channel Response to Various Impacts (Incomplete at this time)

- Some streams and floodplains are more sensitive than others. Describe Source, Transport, Response Reaches
- General effects of human activities (isolation of floodplain, simplification of habitat, alteration of disturbance regime) Physical habitats in rivers of all sizes throughout the Pacific coastal ecoregion have been simplified by human activities (Hicks et al 1991)—from Reeves et al 1998

2.4.1 Channel Response to Channelization

Channelization is the deliberate or unintended alteration of channel slope, width, depth, sediment roughness or size, or sediment load (Bolton and Shellberg 2001). Activities included under the heading of channelization typically include channel widening, deepening, and straightening, levee construction, bank stabilization, and clearing and snagging of live and dead vegetation in and along the river. These channel modifications have typically been done for flood control, to improve drainage of adjacent land, to improve conveyance of boats and logs, to control erosion, and to maximize land use efficiency.

The ecological effects of channelization consist of both physical and biological impacts to the aquatic system. These impacts may be localized or extend up- or down-stream from the channelized reach. The biological effects may be in response to the physical changes in depth, shade, sediment, temperature, altered hydrology, and isolation of floodplain habitats, or they may be in response to changes in nutrient cycling and changes in populations of various trophic levels that get transmitted throughout the biological system.

Channelization often changes the shear stresses experienced on the bed and banks of the channelized reach. Shear stresses are directly proportional to the slope of the channel and the depth of water. If channelization causes water to flow at a higher depth and/or slope than it did in the natural channel, shear stresses will increase causing increased sediment transport. Naturally available bed material that was stable in the natural channel may be flushed through the altered one, causing the bed material to coarsen. If the naturally available bed material, or that placed in the channel, does not contain an adequate supply of material large enough to remain stable in the new channel, the new channel will degrade. This will, in turn, cause possible headcutting, bank instability, and tributary degradation. Downstream effects include deposition of transported sediments, increased flood stage, and loss of channel capacity. Biologic impacts

If channelization causes water to flow at a lower depth and/or slope than it did in the natural channel, shear stresses will decrease causing decreased sediment transport. The channelized reach will likely aggrade. Channel braiding and channel widening may occur in and upstream of the channelized reach. The supply of sediment to downstream channel reaches may decline on at least a temporary basis as the upstream channel adjusts to a new equilibrium. This may impact their vertical stability as material continues to flush out of their system without being replenished. These effects will increase in longevity if the aggraded channel reaches are dredged such that equilibrium is never achieved. Biologic impacts

Channelization activities that tend to increase shear stress on the bed and banks of the channel include channel deepening, loss of floodplain (caused by levee construction or channel deepening), and anything that reduces channel roughness such as bank armoring and removal of live and dead vegetation in and along the river. Channelization activities that tend to decrease shear stress on the bed and banks of the channel include channel widening and channel relocation such that the new channel is perched above the surrounding landscape.

A channel is perched when it does not lie in the lowest part of the landscape. This can occur if the stream is moved to a higher point in the topography to get it out of the way of other landscape activities or to facilitate irrigation. It can also occur as a result of channel aggradation. Perched channels are generally constrained by berms in order to prevent flows from leaving the channel. However, when flow rises above the berms or breaks through the berms, flow leaves the channel. The sediment carrying capacity of the remaining flow in the channel will decrease and sediment will drop out of solution. Perched channels are very susceptible to aggradation and channel avulsion. Biologic impacts

2.4.2 *Channel Response to Changes in Stream Hydrology – **Not Available at this Time***

Changes in stream hydrology will also influence shear stresses experienced in a channel. Increased flow such as that caused by increased levels of impervious surface in developing areas, by a catastrophic dam break, or by natural wet cycles will raise the shear stress on the bed and banks of the channel. Decreased flow such as that caused by stream and groundwater withdrawals and natural drought cycles will tend to decrease shear stress on the bed and banks of the channel.

The channels will eventually reach a new equilibrium shape, planform, and profile over time if not subject to additional watershed perturbations. Time to equilibrium may be years or decades depending on extent and magnitude of watershed disturbance…..Transition and ultimate equilibrium channel may not be desirable to humans. Transition may be harmful to fish and wildlife.

*2.4.3 Channel Response to Changes in Bed Material Supply – **Not Available at this Time***

Increased supply due to reduced sediment detention u/s or landslides or accelerated sediment delivery due to agricultural or urban runoff, altered riparian zone
Decreased supply due to upstream dredging/gravel mining operations, increased u/s detention

*2.4.4 Channel Response to Changes in Supply of Woody Material – **Not Available at this Time***

*2.4.5 Channel Response to Removal of Beaver – **Not Available at this Time***

*2.4.6 Channel Response to Removal of Riparian Vegetation – **Not Available at this Time***

2.5 Influence of Channel Processes and Stream Ecology on Restoration Planning and Design – Not Available at this Time

Protecting or restoring desirable habitat requires that the long-term and short-term ecological processes that produce the features and characteristics of that habitat be protected, maintained or restored (Reeves et al. 1995, Spence et al. 1995).

2.6 References

Allan, J.D. 1995. Stream Ecology: Sturcture and function of running waters. Chapman & Hall, New York. 388pp.

Benda, L. E., D. J. Miller, T. Dunne, G. H. Reeves and J. K. Agee. 1998. Dynamic Landscape Systems. Pages 261-288 In: R. J. Naiman and R. E. Bilby (editors). River

Ecology and Management: Lessons from the Pacific Coastal Ecosystem. Springer-Verlag, New York, New York. pp.705.

Cowx, I. G. and R. L. Welcomme. 1998. Rehabilitation of River for Fish. Fishing News Books, Malden, Massachusetts. pp 260.

Edwards, R. T. 1998. The Hyporheic Zone. Pages 399-429 In: R. J. Naiman and R. E. Bilby (editors). River Ecology and Management: Lessons from the Pacific Coastal Ecosystem. Springer-Verlag, New York, New York. pp.705.

Hershey, A. E. and G. A. Lamberti. 1998. Stream Macroinvertebrate Communities. Pages169-199 In: R. J. Naiman and R. E. Bilby (editors). River Ecology and Management: Lessons from the Pacific Coastal Ecosystem. Springer-Verlag, New York, New York. pp.705

Junk, W. J., P. B. Bayley and R. E. Sparks. 1989. The flood pulse concept in river-floodplin systems, p. 110-127. In D. P. Dodge (editor) Proceedings of the Internationsl Large River Symposium. Canadian Special Publications in Fisheries and Aquatic Sciences. 106.

Leopold, L. B. 1994. A View of the River. Harvard University Press. Cambridge, Massachusetts.

Miller, D. E., P. B. Skidmore and D. J. White. 2001. Channel Design. Prepared by Inter-Fluve, Inc., Missoula, Montana for the Washington Department of Fish and Wildlife, Washington Department of Ecology, and Washington Department of Transportation. pp89.

Naiman, R. J. 1998. Biotic Stream Classification. Pages 97-119 In: R. J. Naiman and R. E. Bilby (editors). River Ecology and Management: Lessons from the Pacific Coastal Ecosystem. Springer-Verlag, New York, New York. pp.705

Reeves, G. H., L. E. Benda, K. M. Burnett, P. A. Bisson and J. R. Sedell. 1995. A disturbance-based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific Northwest. American Fisheries Society Symposium 17:334-349.

Roni, P., T. J. Beechie, R. E. Bilby, F. E. Leonetti, M. M. Pollock and G. R. Pess. 2002. A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific Northwest watersheds. North American Journal of Fisheries Management 22:1-20.

Sedell, J. R., J. E. Richey and F. J. Swanson. 1989. The river continuum concept: A basis for the expected ecosystem behavior of vary large rivers? In D. P. Dodge (editor) Proceedings of the International Large River Symposium. Canadian Special Publications in Fisheries and Aquatic Sciences. 106:49-55.

Spence, B. C., G. A. Lonnicky, R. M. Hughes and R. P. Novizki. 1995. An Ecosystem Approach to Salmonid Conservation, Volume 1: Technical Foundation. Prepared by Man Tech Environmental Research Services Corporation, Corvallis, Oregon, for the National Marine Fisheries Service, U.S. Environmental Protection Agency, and Fish and Wildlife Service.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell and C. E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences. 37:130-137.

Ward, J. V. and J. A. Stanford. 1983. The serial discontinuity concept of lotic ecosystems. In Dynamics of Lotic Ecosystems, Fontaine T. D. and S. M. Barell (editors). Ann Arbor Science Publishers: Ann Arbor, Michigan. 29-42.

Ward, J. V., K. Tockner, U. Uehlinger and F. Malard. 2001. Understanding natural patterns and processes in river corridors as the basis for effective river restoration. Regulated Rivers: Research & Management 17:311-323.

Washington Joint Natural Resources Cabinet. 2001. Guidance on Watershed Assessment for Salmon. Olympia, Washington.